FINAL REPORT for

Edmonton Transit System

Alternative Scenarios for Trolley Bus Replacement

Cost and Environmental Implications

Edmonton
March , 2007

Study Background and Issues

This Study compares the costs and emission implications for three alternative options related to replacing the existing trolley bus fleet…

Option	Description
Baseline (replace old trolleys with new trolleys)	The existing 41 trolley buses would be replaced in 2010 with 47 new trolley buses.
Scenario 1 (replace trolleys with diesel)	The existing 41 trolley buses would be replaced in 2010 with 47 new diesel buses. These buses would meet all prevailing emission standards set by Environment Canada. (Environment Canada's vehicle emission standards are, for the most part, harmonized with those of the US Environmental Protection Agency).
Scenario 2 (replace trolleys with hybrid-diesel)	The existing 41 trolley buses would be replaced in 2010 with 47 hybrid diesel buses.

Data Sources...overview

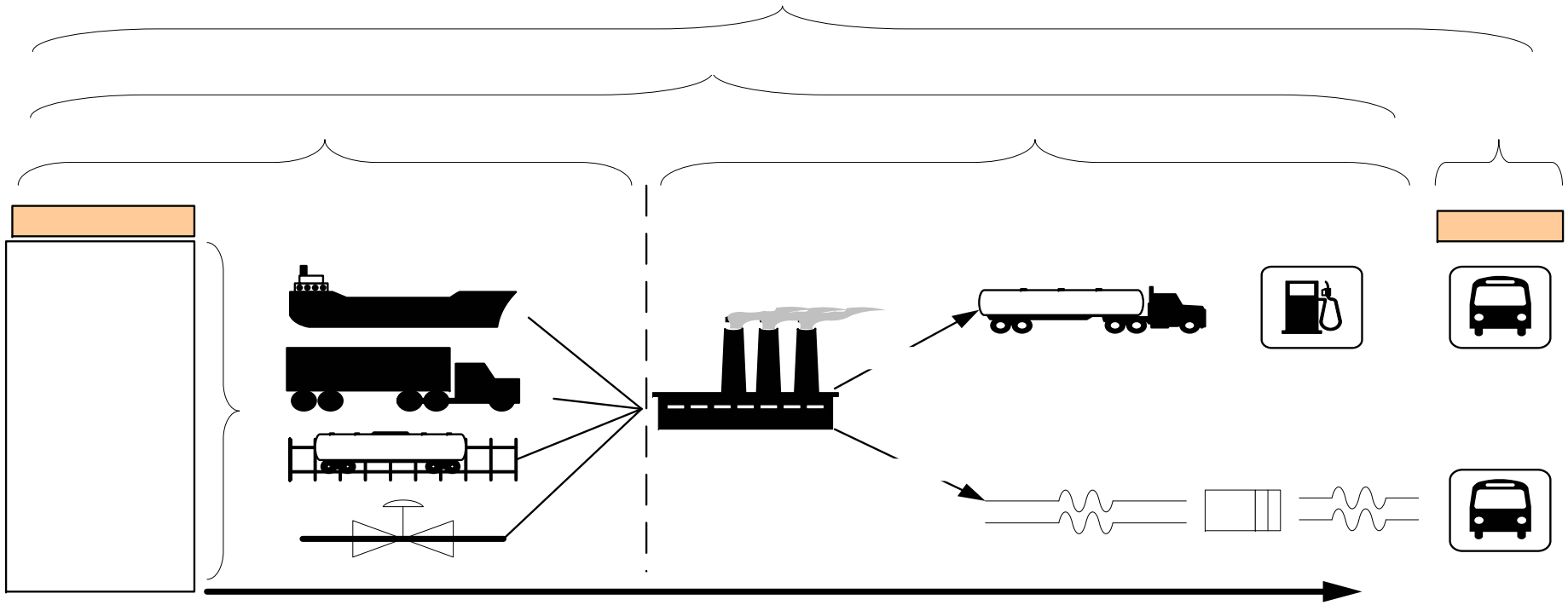
Data Elements, Assumptions and other information used in developing costs and benefits for the three scenarios	Data Source	
	BAH	ETS
Current and future bus fleet inventory by make and model; year-by- year bus retirement and procurement plans through 2027		√
Operating costs data for current fleet including: bus maintenance; raw fuel costs, fuel economy (for both diesel and trolleys), and catenary system operations.		√
Future maintenance costs for the trolley overhead system		√
Capital costs for buses (trolleys, diesels, and hybrids)		√
Projected capital costs for the catenary system through 2027		√
Projected costs for dismantling the trolley system		√
Future bus fleet maintenance costs (trolleys, diesels, hybrids)	√	
Future diesel fuel and electricity costs	√	
Current & future emissions from diesel and hybrid buses (includes well-to-pump emissions)	√	
Current & future emissions from electricity generation: (electricity emission factors do not include well-to-pump emissions: see page 23 for explanation of "well-to-pump" and "well-to-wheel" emissions).		**Epcor**
Projected fuel economy from diesels (kilometers per liter) and from trolleys (kilometers per kWh)	√	

Estimating Emission Inventories from bus operations

Emission Inventories for each Scenario..

- The emissions of most concern from diesel buses are NOx and Particulate Emissions (specifically PM10), *(note: VOC and CO emissions from diesels are inherently extremely low and are generally not reported or discussed when evaluating new heavy-duty propulsion technologies.)*
- The health and environmental issues associated with NOx and PM10 emissions can be found in numerous sources from the US EPA and Environment Canada—and are discussed in the 2003 BAH Report.
- Greenhouse Gas Emissions, (principally CO_2), is also an effluent of concern as evidence continues to point to its impacts on global warming.
- The focus of the emissions inventory analyses is therefore on NOx, PM10 and CO2 (although other regulated emissions are also reported as a matter of convenience)

Emission factors (in terms of grams per kilometer) from buses are based on total “well-to-wheel” (WTW) emissions…



The emissions data for each portion of the fuel supply chain were derived from a variety of sources..

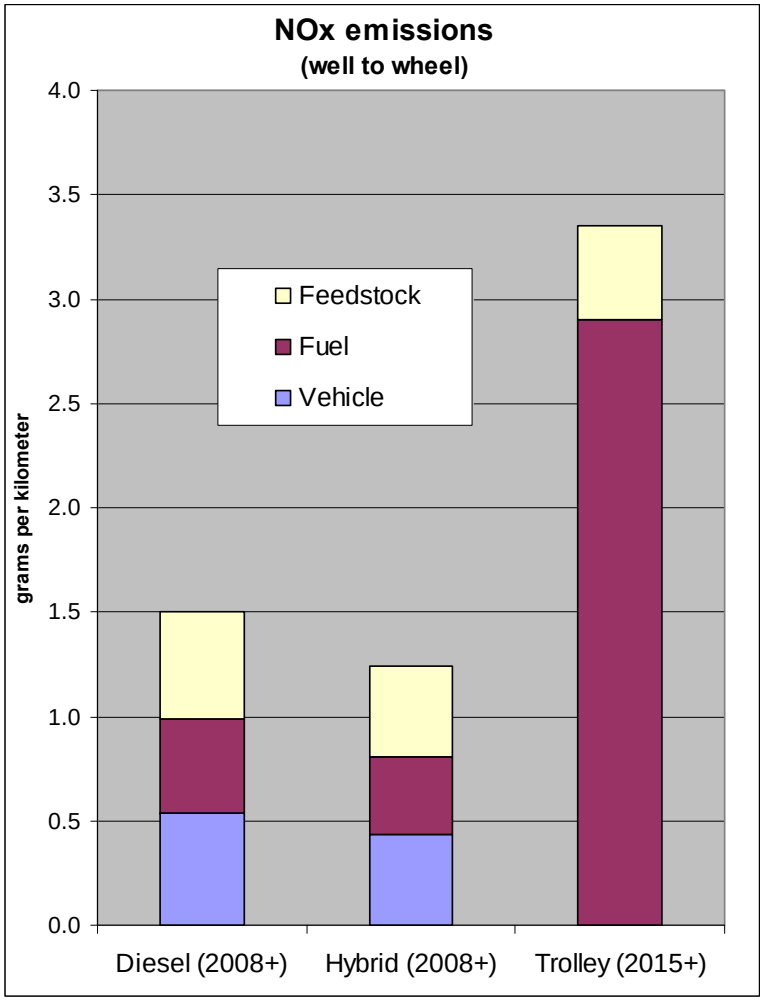
Emissions Component (within total well-to-wheel emissions)	Source of Emission Factor Data	
	Diesel and Hybrid Buses	Trolley
Vehicle (emissions from the vehicle itself, or "tailpipe" emissions)	EPA Mobile 6.2 Model	There are zero emissions at the vehicle level
Fuel (emissions associated with refining of crude and transportation of final product to the "pump"; or, for electricity, emissions associated with generating plants)	Argonne National Labs "GREET" Model	Data Supplied by EPCOR
Feedstock (emissions associated with extraction of raw feedstocks and distribution to refining and/or generating facilities).	Argonne National Labs "GREET" Model	Argonne National Labs "GREET" Model

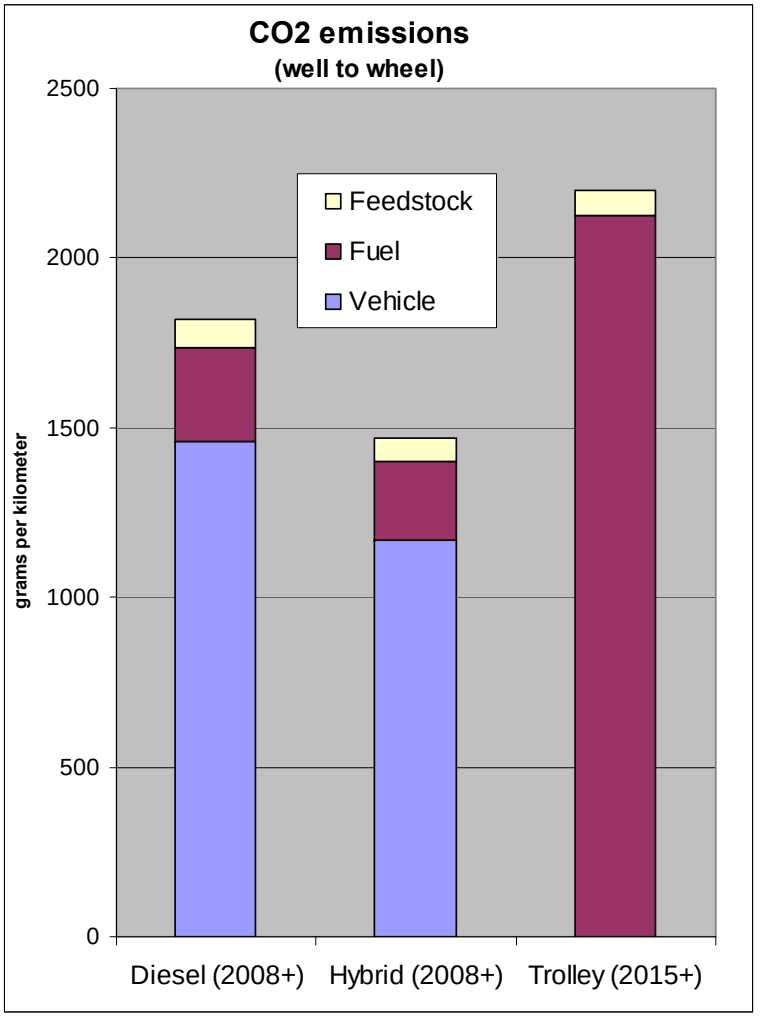
A note about reliability and relevance of each emissions component…

Emissions Component	Reliability of Estimates	Relevance
Vehicle	Vehicle emission factors are deemed highly reliable as they are derived from empirical test data.	Very relevant since these emissions occur at “street” level.
Fuel	Deemed reasonably reliable as data was supplied by EPCOR (for generating facilities); and, emissions from refinery operations are fairly well known and characterized.	Relevant since refineries and generating facilities are within the Edmonton region.
Feedstock	These estimates are the least reliable. They have been developed based on nationwide estimates and are not tailored to reflect the Edmonton energy supply scenario.	Less relevant since these emissions will be generated outside the Edmonton region. (although CO2 emissions are of global concern and therefore proximity of the source to Edmonton is not particularly relevant.

Emissions Modeling Results

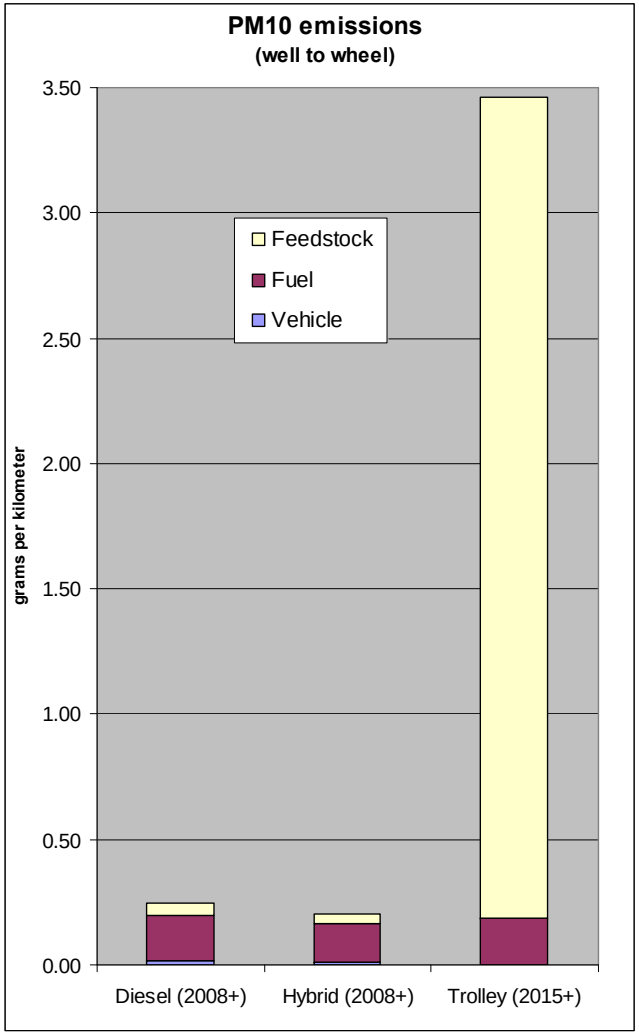
Trolleys will yield higher well-to-wheel NOx and Greenhouse Gas emissions (CO2) than diesels or hybrids

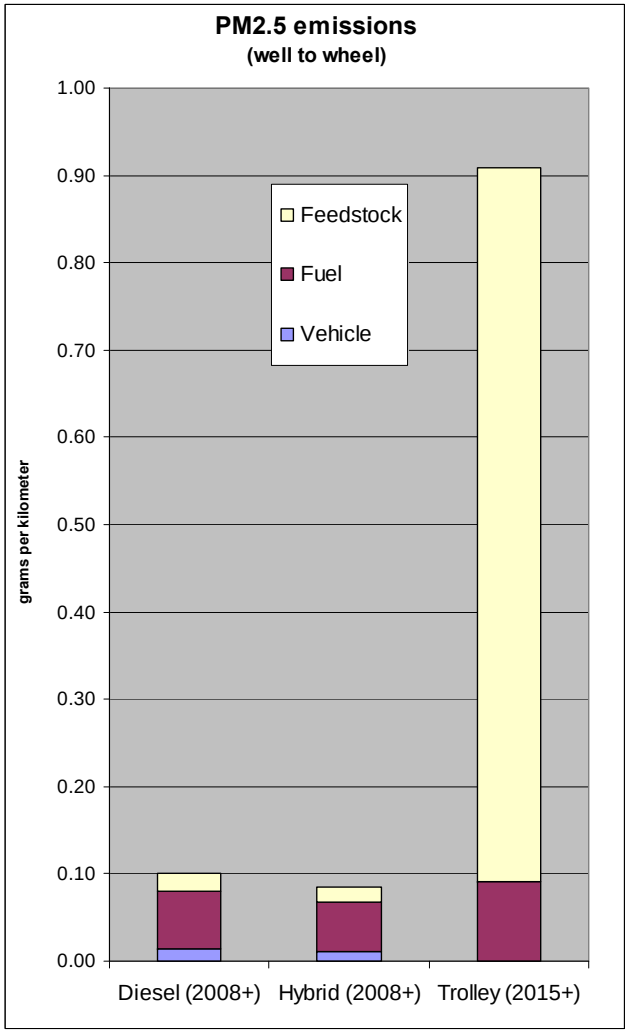




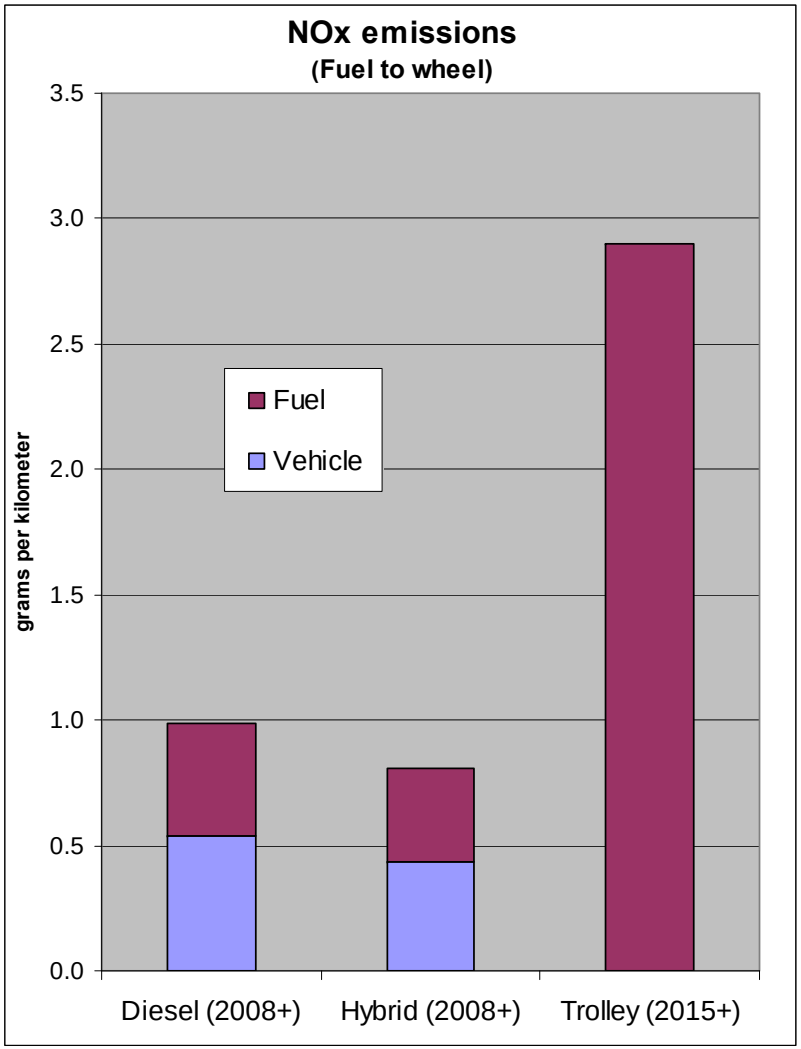
Well to wheel PM10 and PM2.5 emissions…

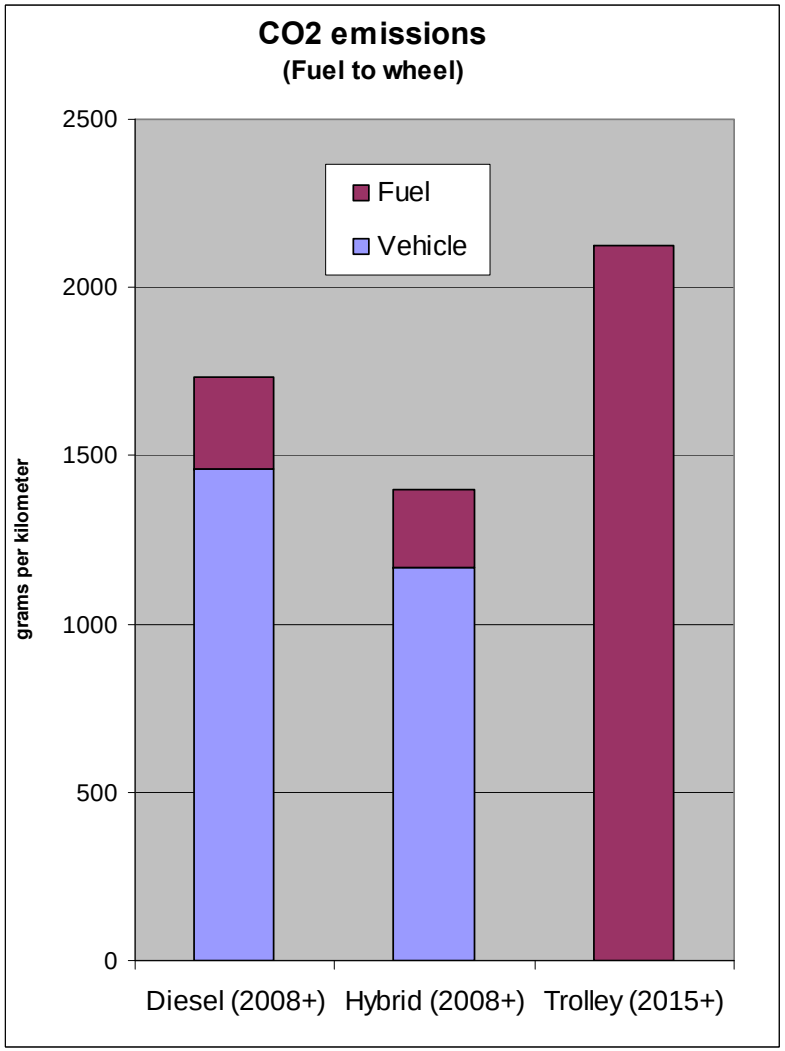
- Trolley operation will result in much higher PM emissions due primarily to emissions associated with mining, extraction and supply of coal (feedstock) to the power-plant facilities.
- However, it should be noted that PM emissions associated mining of coal (i.e., feedstock related PM emissions) are suspected to quickly precipitate out of the atmosphere.
- For the above reason, and because "feedstock" emissions generally occur outside the immediate Edmonton area, and because such estimates are less reliable than "vehicle" and "fuel" estimates, we would recommend focusing on "vehicle + fuel" emissions in considering the environmental impacts of trolleys and diesel buses.



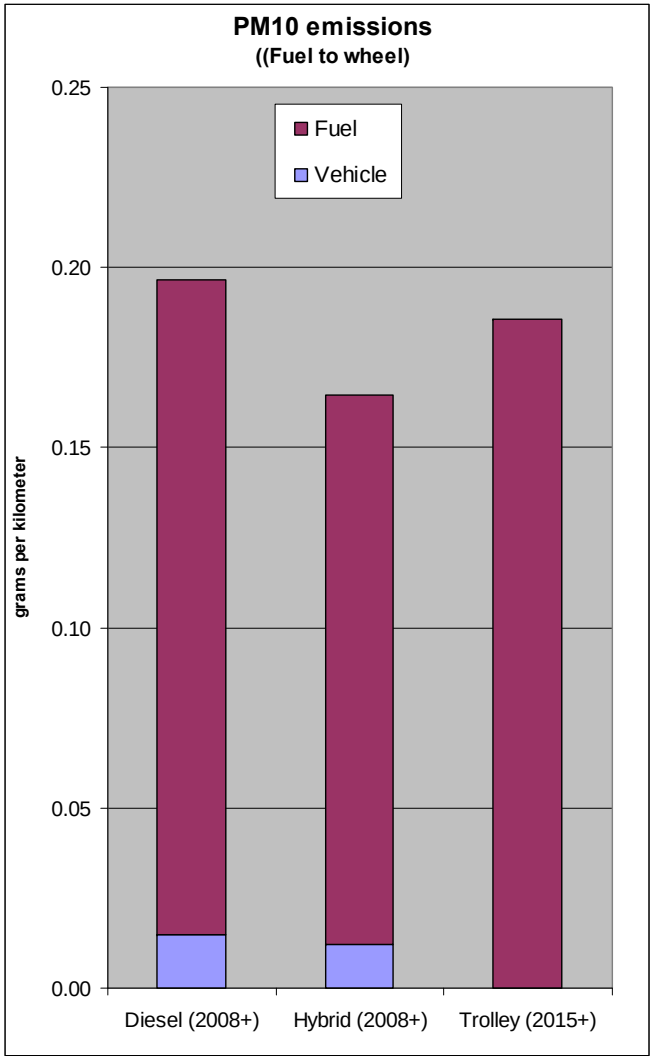


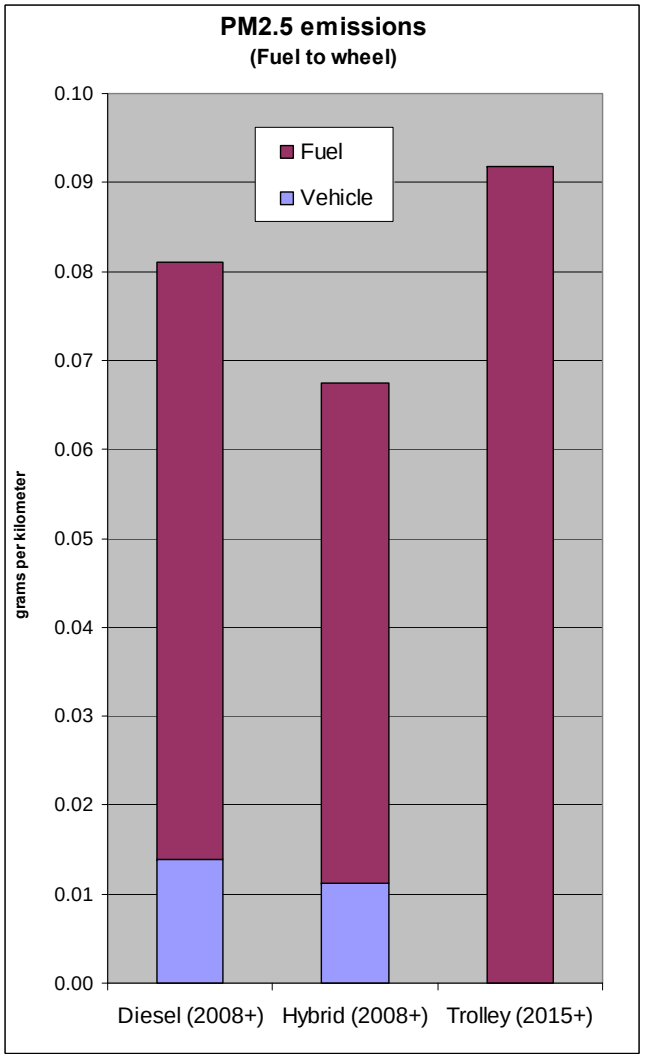
If we exclude emissions associated with the “feedstock”, the NOx and CO2 emissions from trolleys (or actually the powerplants supplying trolleys with electricity) are higher than for the diesel and hybrid buses





Excluding the emissions associated with feedstock supply, the PM emissions are roughly equivalent for diesels and trolleys





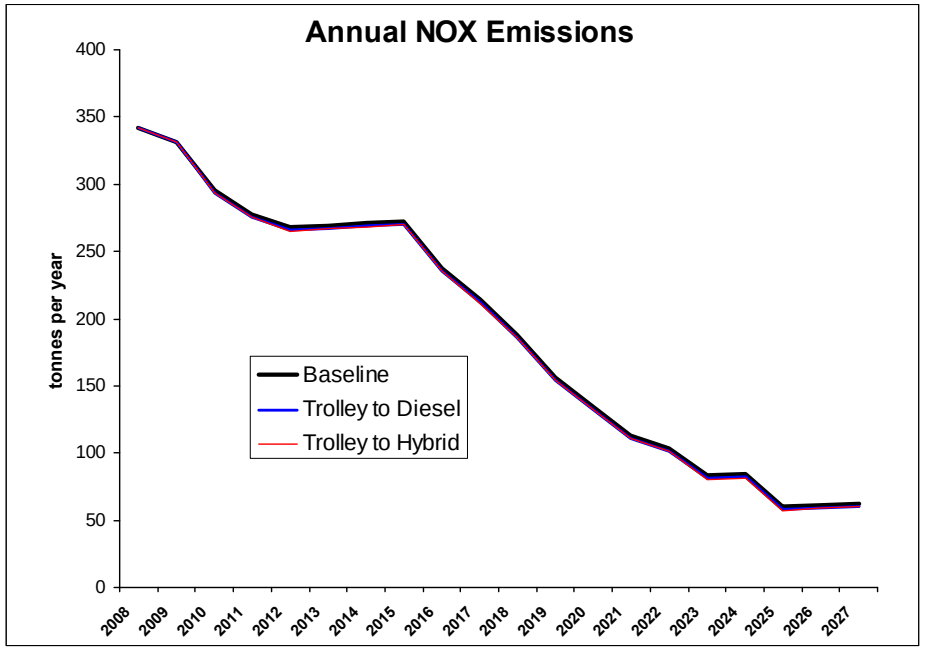
There is very little difference in overall fleet emissions among the three scenarios evaluated.

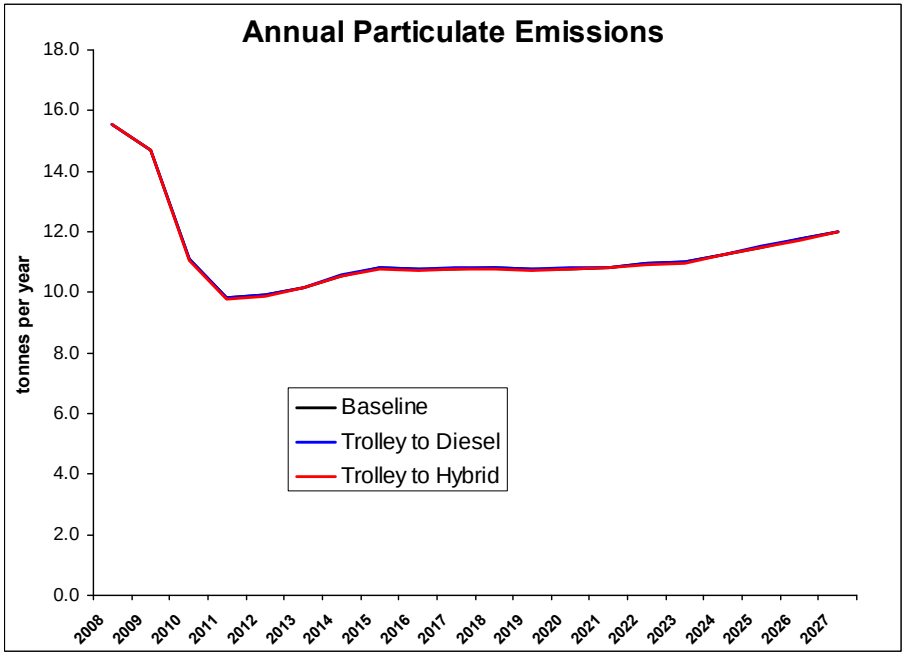
Forecasted Annual Emissions from Bus Fleet Operations (tonnes)									
Scenario Description	NOX			PM			CO2		
	2007	2017	2027	2007	2017	2027	2007	2017	2027
Renew Trolley Fleet in 2010 (Baseline)	345.05	213.87	62.38	15.54	10.79	12.01	63,440	83,709	106,047
Scenario 1: Trolley to Diesel	345.05	211.72	60.24	15.54	10.81	12.02	63,440	83,271	105,608
Scenario 2: Trolley to Hybrid	345.05	211.52	60.03	15.54	10.77	11.98	63,440	82,893	105,231

Forecasted Percentage Change in Bus Fleet Emissions									
Scenario Description	NOX			PM			CO2		
	2007	2017	2027	2007	2017	2027	2007	2017	2027
Renew Trolley Fleet in 2010 (Baseline)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 1: Trolley to Diesel	0.0%	-1.0%	-3.4%	0.0%	0.1%	0.1%	0.0%	-0.5%	-0.4%
Scenario 2: Trolley to Hybrid	0.0%	-1.1%	-3.8%	0.0%	-0.2%	-0.2%	0.0%	-1.0%	-0.8%

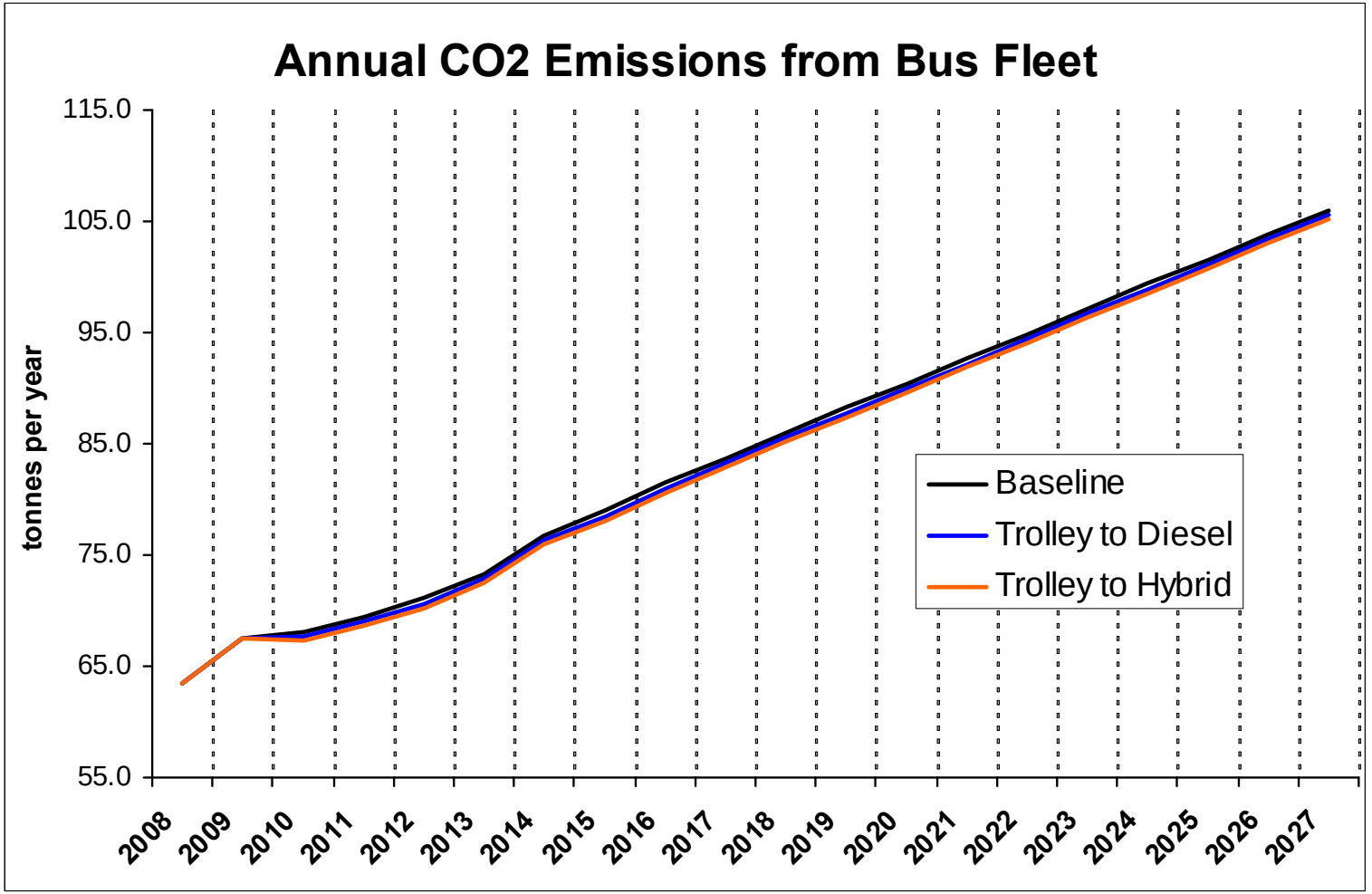
The good news from an environmental perspective is that in spite of substantial fleet growth, regulated emissions from the fleet will decline during the study period (2007 to 2027)

- The ETS fleet is forecast to grow from approximately 900 buses in 2007 to 1,500 buses in 2027.
- However, because older (higher polluting) buses will be retired over the next decade—and replaced with new "clean diesel" technology, the emissions from the fleet decline.





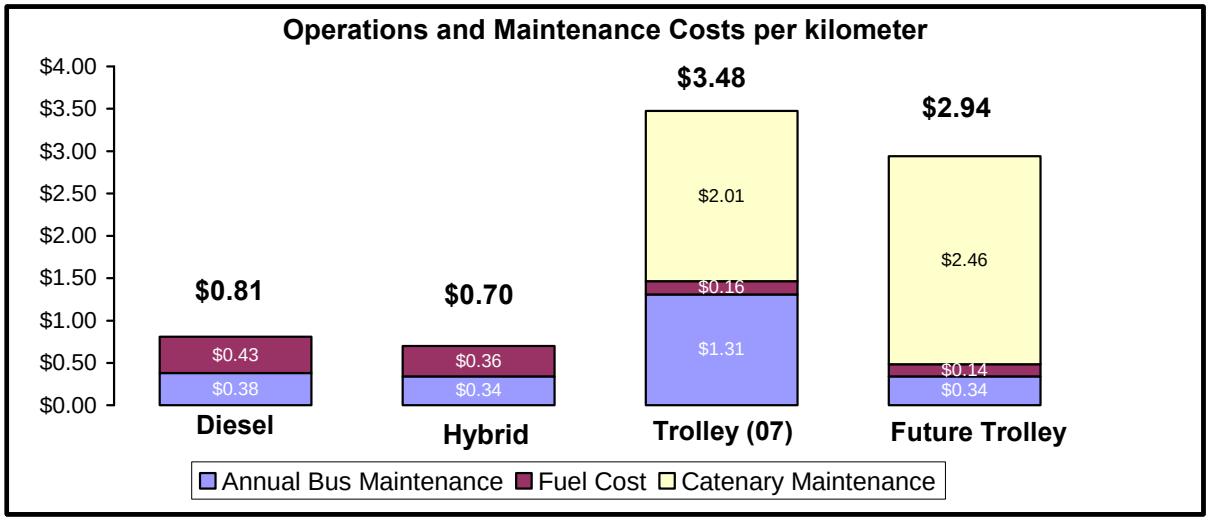
This same story does not hold true for Greenhouse Gas emissions…

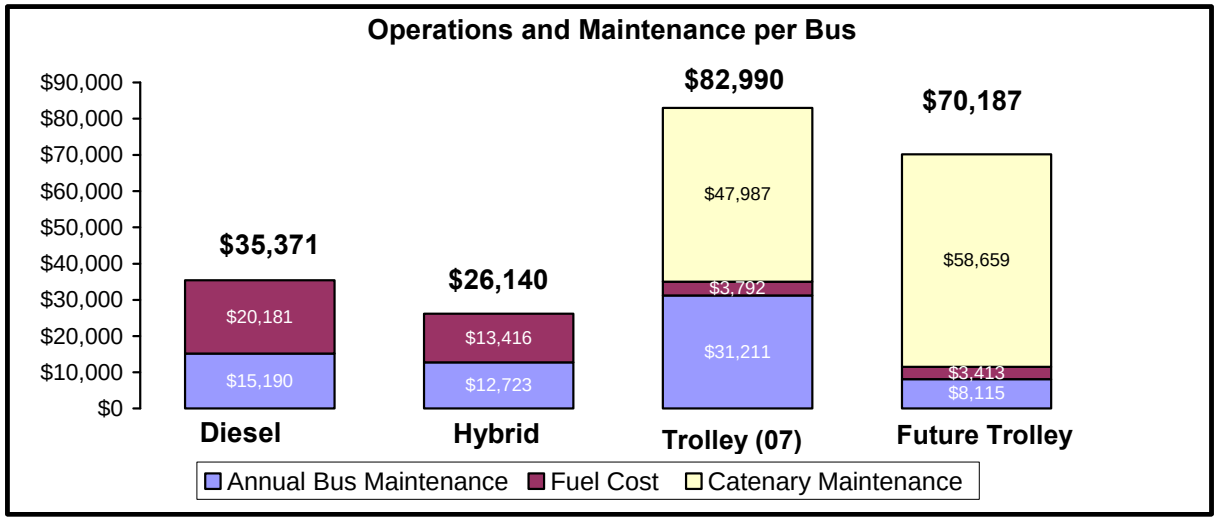


Financial Results

Overall maintenance costs for trolleys are significantly higher than for diesel buses…

- Direct bus maintenance and fuel costs are similar between diesels and trolleys, however,
- The cost of maintaining the overhead catenary system must be added to the cost of trolleys.
- Even after adjusting for annual differences in utilization, (diesel buses accumulate higher annual kilometers due to route assignments), the diesel buses are still far less expensive to operate and maintain than trolley buses.

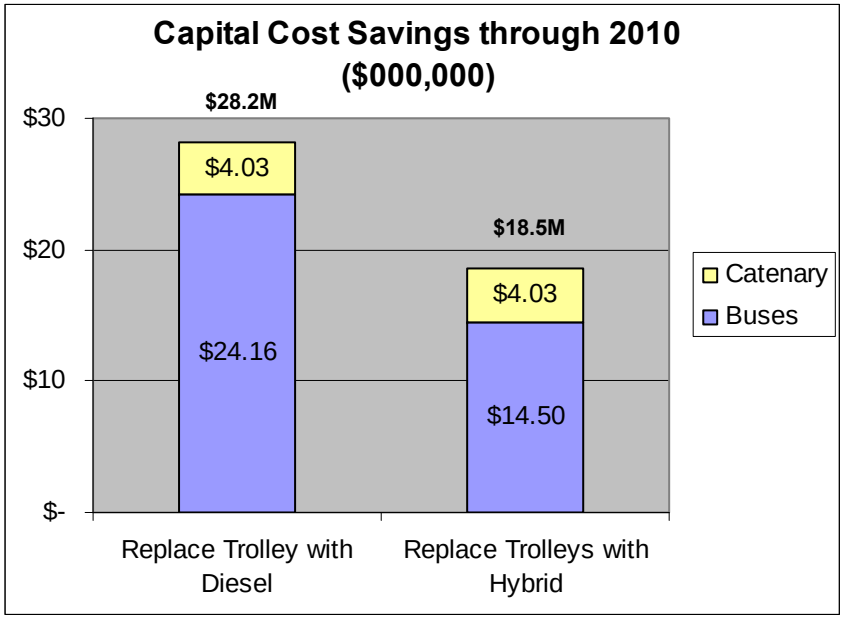


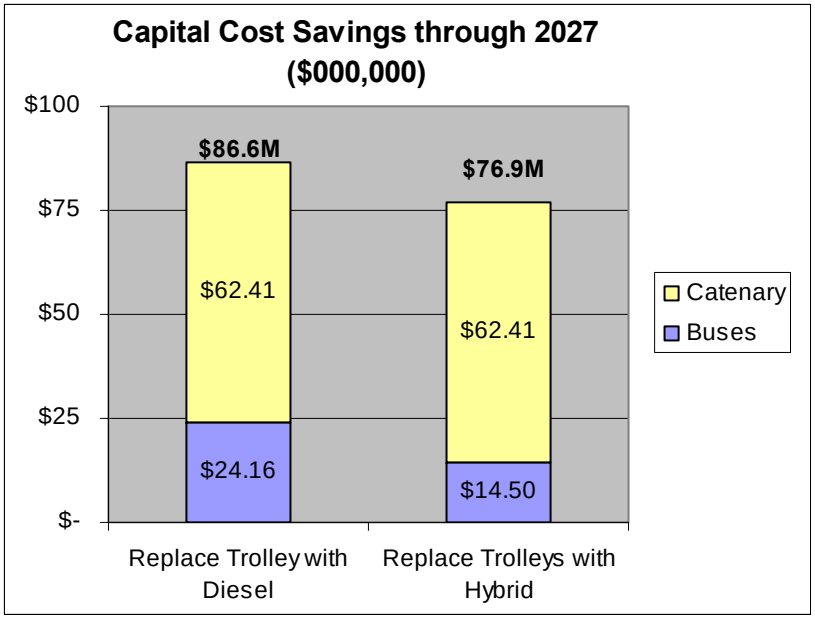


Capital cost Savings…

- Replacing the trolley buses with diesel buses would save $28M in capital costs through year 2010…and is due largely to reduced bus costs ($24M) as well as reduced catenary capital expenditures ($4M). Replacing trolleys with hybrids also results in a savings, but is reduced to $18M due to the higher cost of the hybrid buses.

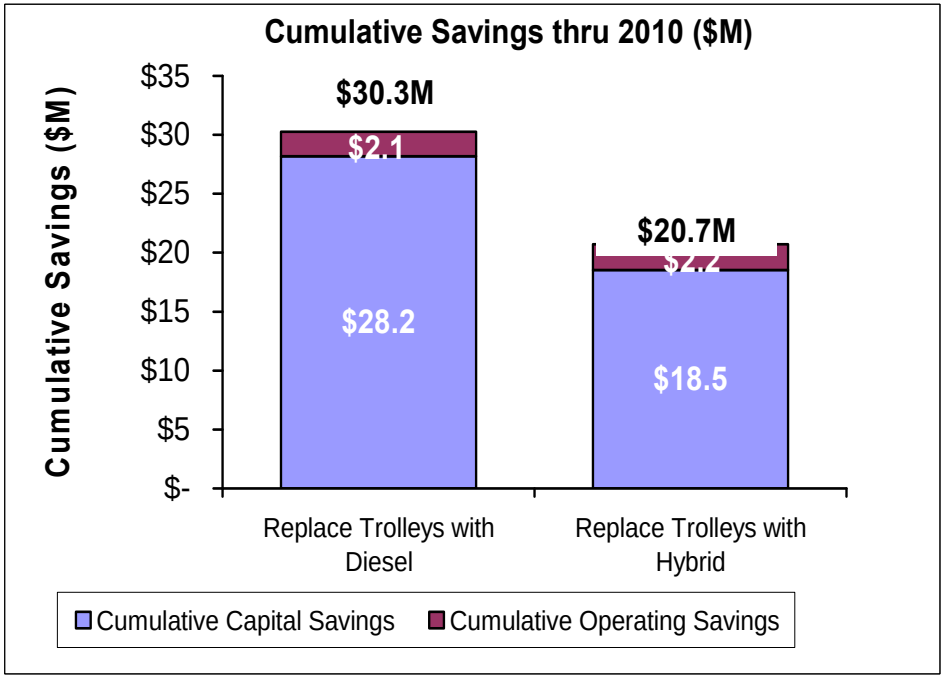
- Over the next 20 years, replacing trolley buses with diesel buses would result in $87M capital savings due largely to elimination of catenary system capital costs.

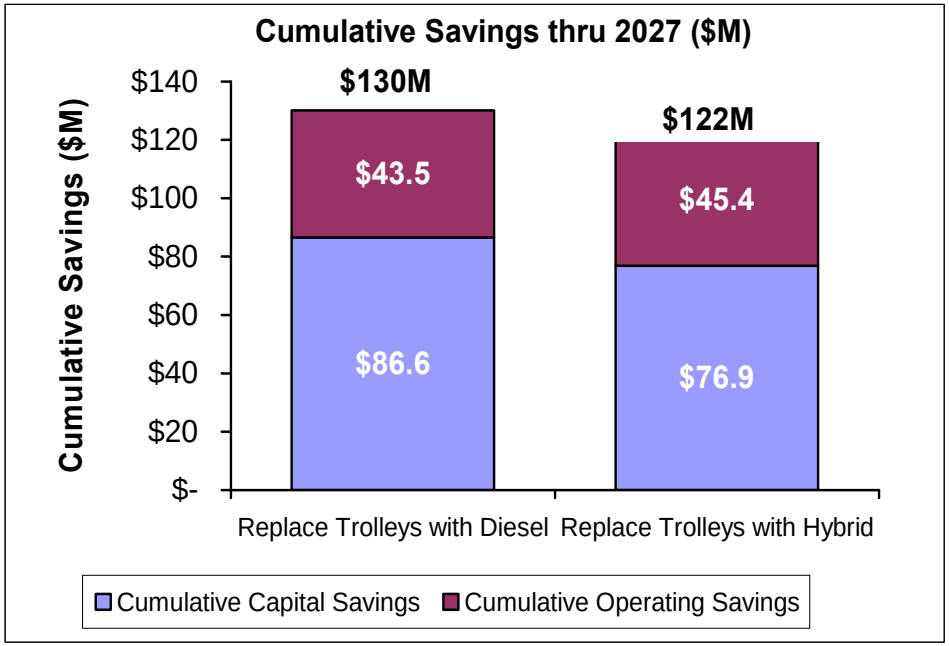




Cumulative capital plus operating savings…

- Replacing trolley buses with diesel buses results in a total savings of $30M through 2010, and $130M through 2027
- There is little operating savings through 2010 since it is presumed that trolleys would continue to operate through 2009 in both scenarios 1 and 2.
- Scenario 2 (replace trolleys with Hybrids) would result in slightly more operating cost savings (compared to replacing trolleys with diesels) as a result of the improved fuel economy of hybrids.





Year-by-year savings resulting from replacing trolleys with diesels (scenario 1) or with hybrids (scenario 2)…